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APPLICATION OF CERES-WHEAT MODEL TO SIMULATE GROWTH, DEVELOPMENT AND RADIATION USE EFFICIENCY OF WHEAT CROP

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CERES-WHEAT Model is an important technique to assess growth, development and radiation use efficiency skills of wheat crop. Under changing climatic conditions world over, one of the suitable approach is needed to enhance the growth and reproductive skills of field crops. For the purpose, a field trial was conducted at Adoptive Research Farm Sargodha. The study comprised of four fertilizer levels *viz.* control (Recommended dose), 84, 114, 144 kg ha^{-1} and three irrigation levels *viz.* irrigation at crown root + jointing + milking, at crown root + booting + grain filling, and at jointing + booting + grain filling. Irrigation levels were kept in main plots and fertilizer levels were randomized in subplots. Data revealed that Crop Growth Rate (CGR), Leaf Area Index (LAI), Leaf Area Duration (LAD) and Net Assimilation Rate (NAR) were significantly increased by increasing the fertilizer levels as well as irrigation frequency. Maximum grain yield 5528 kg ha^{-1} was obtained while irrigating the crop at jointing + booting + grain filling stages using 144 kg ha^{-1} of nitrogen. Interestingly, increase in fertilizer rate increased the yield and yield components and plant growth and radiation use efficiency. In conclusion, three irrigations at jointing + booting and grain filling stage and fertilizer levels as 144 kg ha^{-1} is the best combination for having maximum output in terms of yield of the cultivar Bakhar-2000.

Keywords: CERES-WHEAT Model, Growth and Development, Radiation Use Efficiency

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important food grain crop grown in the world. Due to its immense and multipurpose use in daily life, the prosperity and wellbeing of Pakistan depend upon good harvest of wheat crop. Water is vital to every stage of wheat plant development from seed germination to plant maturation. Stage of the crop is very important for water requirement that is related to moisture sensitive period. If moisture sensitive periods could be identified for wheat crop under field conditions, it would have important implications for irrigation practices. Irrigation applied at sensitive stage would be a valuable management practice for improving yield (Jana *et al.,* 1995; Garabet *et al.,* 1998).

Nitrogen occupies a conspicuous place in plant metabolism. All vital processes in plant are associated with protein, of which nitrogen is an essential constituent. Consequently to get more crop production, nitrogen application is essential in the form of chemical fertilizer. Proper use of nitrogen fertilizer is also considered for farm profitability and environment protection (Makowski *et al*., 1999).

Low availability of soil nitrogen in limited water could be an additional yield reduction factor (Osborne *et al*., 2002). Nitrogen is an integral part of chlorophyll, which is the primary absorber of light needed for photosynthesis. Both water stress and deficiency of nitrogen severely inhibit photosynthesis and hence crop productivity (Kao and Forseth, 1992; Osborne *et al*., 2002).

This study focuses upon the determination of the optimum water and nitrogen requirements of the crop. It can help to identify the growth stages in wheat more sensitive to water deficit conditions and to determine the effect of different levels of irrigation and nitrogen on growth, development and yield of wheat. The research was conducted in agro-climatic conditions of Sargodha at the Adaptive Research Farm Sargodha.

MATERIALS AND METHODS

To assess the effect of different levels of irrigation and fertilizer on growth, development and yield of wheat cv-Bhakhar-2000, a field trial was conducted at the Adaptive Research Farm Sargodha. The crop was sown using seed rate 125 kg ha^{-1} with the help of single row hand drill in 25 cm apart rows. Net plot size was 1.7 m ×10m. The experiment was laid out in a randomized complete block design (RCBD) in a split plot arrangement with three replicates. Experiment comprised of four nitrogen levels *viz.* F1= control (Recommended dose), F2= 84, F3= 114 and F4= 144 kg ha^{-1} and three irrigation levels *viz.* I1= at crown root + jointing + milking, 12= crown root + booting + grain filling and I3= at jointing + booting + grain filling. Phosphorus @ 100 kg ha^{-1} was applied to all plots at the

time of sowing. Half nitrogen was applied at sowing and remaining half was applied with first irrigation. All other cultural practices were kept uniform for all treatments.

Various observations regarding growth, development, yield and yield components, and light interception were recorded during entire course of the study. A randomly selected area of half meter long row was harvested at about two week interval. Sun dried samples were kept in oven at 60^0C to get dry weight and Crop Growth Rate (CGR) was calculated by using the formula of Hunt (1978). Leaf Area Index (LAI) was recorded at two week interval using PAR ceptometer (Accu PAR, Decangon Inc., U.S.A.) directly in the field. Leaf Area Duration (LAD) and Net Assimilation Rate (NAR) were calculated by following the equation of Hunt (1978). Ten plants randomly selected were harvested and then averaged to record yield components by using standard procedure. Crop was manually harvested at maturity and sun dried to get biological yield with the help of a spring balance. Sun dried samples were threshed and grain yield was noted.

Modeling

The fraction of intercepted radiation (Fi) was estimated from LAI following the exponential equation suggested by Monteith and Elston (1983). Radiation Use Efficiency (RUE) for TDM and grain yield was calculated as the ratio of total biomass and grain yield to accumulated intercepted PAR. CERES-WHEAT model was calibrated using the experimental data on development, growth, biomass and grain yield of the wheat. An online version for simulation of crop growth and yield of Decision Support System for Agro-technology Transfer DSSAT was used (Hoogenboom *et al.*, 1994).

Statistical analysis: Data were analyzed statistically by using MSTAT-C software on computer. Least significance difference (LSD) test at 5% probability level was applied to compare the treatments means (Steel *et al.,* 1997). Microsoft Excel was used for the graphical presentation.

RESULTS AND DISCUSSION

Plant height: Among the irrigation levels I_1 (irrigation applied at crown root, jointing and milking) enhanced more plant height as compared to I_2 and I_3 (irrigation applied at jointing + booting and grain filling) levels i.e. 65.11, 63.28 and 63.89cm, respectively. Rajput *et al.* (1994) also reported that irrigation frequencies had significant effect on plant height (Table 2). Similarly among the fertilizer levels maximum plant height was recorded in F_4 (144 kg ha^{-1}) as 75.71cm closely followed by 65.80cm from F_3 (114 kg ha^{-1}) and minimum plant height (55.00cm) was recorded where low doses of fertilizer were used (Table 2). All treatments significantly enhanced the plant height over control treatment (F_1). These results are in conformity with those of Gwal *et al.* (1999), Khaliq *et al.* (1999) and Jan *et al.* (2002) who also observed an increase in plant height due to nitrogen fertilization.

Number of spikelet per spike**:** The treatment differences among various irrigation levels were non-significant (Table 1). However, irrigation applied at crown root + jointing and milking (I_1) showed good results (15.95) followed by (15.87) and I_3 (15.76). Moreover, fertilizer application significantly affected the number of spikelets in a spike with maximum value 17.74cm at F_4 (144 kg ha^{-1}) closely followed by 16.67cm F_3 (114 kg ha^{-1}). Minimum number of spikelet per spike was observed in F_1 level where fertilizer level was low (Table 2). Islam *et al.* (2002) also reported that the spikelet per spike increased significantly with increasing level of fertilizer dose. The interaction between irrigation and fertilizer level was found to be non-significant (Table 1).

Number of productive tillers**:** Although treatment differences among irrigation levels were non-significant (Table 1). However, irrigation applied at crown root + booting and grain filling resulted maximum number of productive tillers (293.42). Matsunaka *et al.* (1992), Ghazal *et al.* (1998) and Zbeic *et al.* (1998) also reported that productive tillers m^{-2} increased as irrigation increased. As far as the fertilizer levels are concerned that produce a significant effect on number of productive tillers. It was observed that number of productive tillers was increased from low fertilizer rate to higher doses. Maximum number of productive tillers (311.67) were recorded in the treatment F_4 (144Kg ha^{-1}) where maximum fertilizer was used followed by F_3 (114Kg ha^{-1}) where number of productive tillers was 292 recorded. Minimum number of productive tillers was recorded in F_1 (control) where fertilizer dose was very low as compared to the others (Table 1). Maqsood *et al.* (2002) also reported that irrigation at critical growth stages and application of 144Kg ha^{-1} fertilizer gave the highest number of productive tillers. These results are quite in line with those of Abd–Gaward *et al.* (1993), Sabry *et al.* (1999) and Islam *et al.* (2002). The interaction between irrigation and fertilizers levels was found to be non-significant (Table 1).

Number of grains per spike: Differences among the treatments of irrigation levels was non-significant. Maximum numbers of grains per spike (36.80) were observed when irrigation applied at crown root + jointing and milking stage (Table 1). Maqsood *et al.* (2002) also reported that the application of irrigation at the crown root, booting and anthesis stage gave the highest number of grains per spike but these results are in contrast with the results of Ghazal *et al.* (1998) reported that irrigation was less important than fertilizer on kernels per spike. However, differences among the treatments of fertilizer levels were significant. Maximum number of grains (40.93) produced in a spike was recorded in the treatment using F_4 (144 Kg ha^{-1}) fertilizer level where fertilizer

Table 1. Influence of different irrigation and fertilizer levels on spikelets/spike, productive tillers, grains/spike, spike length and grain yield of wheat

Treatments	Spikelets/spike	Productive tillers (m^{-2})	Grains/spike	Spike length (cm)	Grain yield (Kg/Acre)
Irrigation levels					
I_1	15.95	284.00	36.80	14.80	515.09
I_2	15.87	293.42	36.63	14.61	538.99
I_3	15.76	268.00	36.38	14.70	595.98
SX	0.126	10.085	0.290	0.12	22.719
Significance	ns	ns	ns	ns	ns
Nitrogen levels					
F_1	13.48d	248.0d	31.10d	13.45d	452.01d
F_2	15.56c	275.56c	35.90c	14.24c	487.30c
F_3	16.67b	292.0b	38.47b	15.21b	569.59b
F_4	17.74a	311.67a	40.93a	15.90a	691.17a
LSD 5%	0.411	11.69	0.947	0.428	43.51
SX	0.138	3.935	0.319	0.144	14.643
Significance	**	**	**	**	**
Interaction	ns	ns	ns	ns	ns
Mean	64.09	281.80	36.60	14.70	550.02

Figures sharing same letter did not differ significantly at $P \leq 0.05$, I_1= at crown root + jointing + milking, I_2=at crown root + booting + grain filling, I_3=at jointing + booting + grain filling, F_1= control (Recommended dose), F_2=84 kg/ha^{-1}, F_3=114 kg/ha^{-1}, F_4=144 kg/ha^{-1}, *=Significant, **=highly significant, ns= non-significant

Table 2. Influence of different irrigation and fertilizer levels on plant height, net assimilation rate, RUE (TDM), RUE (grain) of wheat

Treatments	Plant height (cm)	Net Assimilation Rate ($gm^{-2}d^{-1}$)	RUE (TDM) (g MJ^{-1})	RUE (grain) (g MJ^{-1})
Irrigation levels				
I_1	65.11	6.18	3.88	650.85
I_2	63.28	6.45	4.36	644.45
I_3	63.89	6.31	4.57	814.82
SX	0.788	0.273	0.246	301.14
Significance	ns	ns	ns	ns
Nitrogen levels				
F_1	55d	5.90d	2.93d	562.24d
F_2	59.86c	6.43b	4.19b	628.11c
F_3	65.80b	6.68a	4.13c	766.21b
F_4	75.71a	6.25c	5.84a	856.92a
LSD 5%	2.448	0.338	0.327	0.526
SX	0.824	0.180	0.180	55.366
Significance	**	**	**	**
Interaction	ns	ns	ns	ns
Mean	64.09	6.31	4.27	703.37

Figures sharing same letter did not differ significantly at $P \leq 0.05$, I_1= at crown root + jointing + milking, I_2=at crown root + booting + grain filling, I_3=at jointing + booting + grain filling,F_1= control (Recommended dose), F_2=84 kg/ha^{-1}, F_3=114 kg/ha^{-1}, F_4=144 kg/ha^{-1}, *=Significant,**=highly significant, ns= non significant, RUE=radiation use efficiency, TDM=total dry matter

dose was maximum, closely followed by 38.47 from F_3 (114 kg ha^{-1}). The number of grains per spike increased by increasing the fertilizer dose. All treatments differed significantly over control (Table 1). These findings are in agreements with those of Ghazal *et al*. (1998), Gwal *et al.* (1999), Khaliq *et al*. (1999), Sabry *et al.* (1999), Ali *et al.* (2000), Islam *et al.* (2002), Maqsood *et al.* (2002) and Sabir *et al.* (2002). The interaction between irrigation and fertilizer levels on number of grains per spike was non-significant. Wheat plots fertilized with 144 kg ha^{-1} and irrigated at jointing + booting and grain filling stages produced maximum number of grains per spike (Table 1).

Spike length: Maximum spike length 14.80 cm was observed when irrigation applied at crown root + jointing and milking (Table 1). Rajput *et al.* (1994) also found that irrigation frequencies had significant effect on spike length. However, differences among the treatments of fertilizer level were significant. Maximum spike length 15.90cm was recorded at F_4 fertilizer level (144 Kg ha^{-1}), where fertilizer dose was maximum and vice versa. It is clear from the results that spike length could be increased by increasing the fertilizer dose. The treatments also significantly differed over the control (Table 1). These findings are supported by Gwal *et al.* (1999) and Ali *et al*. (2000). The interaction between irrigation and fertilizer levels for spike length was non-significant. The combination of I_3 and F_4 was the best as compare to all other combinations with respect to spike length (Table 1).

Grain yield: Among the irrigation levels**,** I_3 (irrigation applied at jointing + booting and grain filling) enhanced more grain yield as compared to I_2 (irrigation applied at

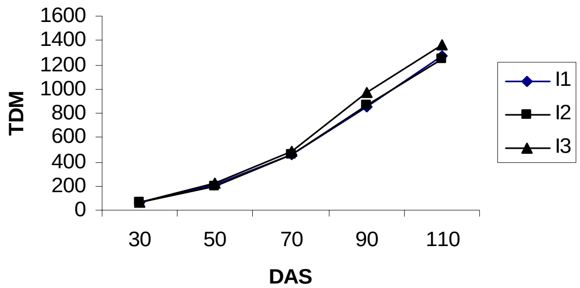

Figure 1 a. Effect of Different Irrigation levels on TDM with DAS

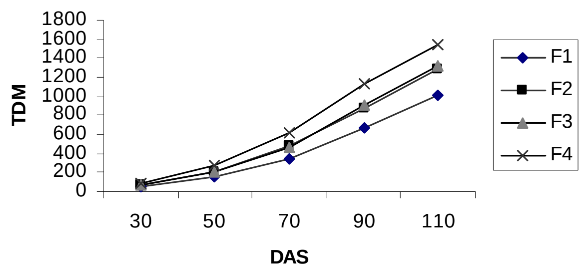

Figure 1 b. Effect of different fertilizer levels on TDM with DAS

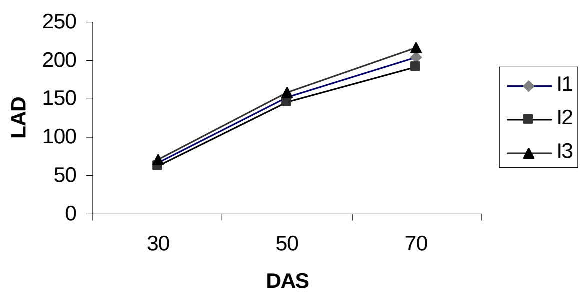

Figure 2 a. Effect of different irrigation levels on LAD with DAS

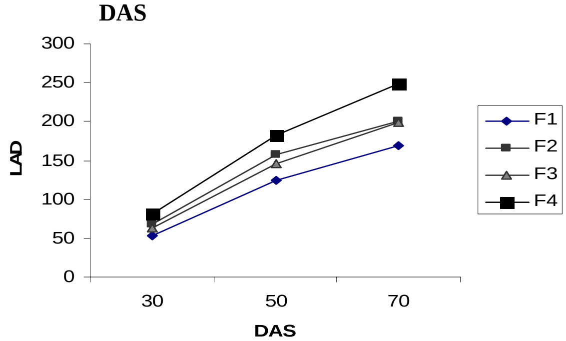

Figure 2 b. Effect of different fertilizer levels on LAD with DAS

crown root + booting and grain filling) and I_1 (irrigation applied at crown root + jointing and milking) levels as 595.98, 538.99 and 515.09 Kg acre^{-1} respectively (Table 1). These findings are supported by Abderrazak *et al.* (1995), Clobanu *et al.* (1995) and Oweis *et al.* (1999). Similarly among the fertilizer levels maximum grain yield 691.17 Kg acre^{-1} was recorded from F_4 (144 kg ha^{-1}) followed by 569.59 Kg acre^{-1} from F_3. Fertilizers had strong influence on yield of grain. Minimum 452.01 Kg acre^{-1} was recorded where low doses of fertilizer were used. The perusal of the table also showed that grain yield significantly increased with increasing fertilizer levels. There were significant differences among treatment means for grain yield (Table 1). The results are quite in line with Lathwal and Singh (1992), Karim *et al.* (1997), Rajendar *et al.* (1998), Ali *et al.* (2000), Khan *et al.* (2000), Nazir *et al.* (2000), Jan *et al.* (2002) and Hameed *et al.* (2003). The interaction between irrigation and fertilizer levels was found to be non-significant (Table 1).

Growth, radiation use efficiency and modeling growth

Total dry matter accumulation: The growth in all treatments was slow until 50 Days After Sowing (DAS), there after Total Dry Matter (TDM) accumulation was fast throughout the season. Total dry matter accumulation was significantly affected till final harvest (110 DAS) by the treatments. All irrigation levels showed non-significant effect on the total dry matter accumulation. However, maximum TDM 1360.50 g m^{-2} from irrigation applied at jointing + booting and grain filling was observed after 110 DAS. Minimum total dry matter accumulation 1265.70 g m^{-2} at final harvest was observed from irrigation applied at crown root + jointing and milking which was statically at par with 1246.26 g m^{-2} from irrigation applied at crown root + booting and grain filling. Over all mean TDM production was 1290.81 g m^{-2} during the season (Fig. 1a). Chandra and Kumar (1999) also reported that total dry matter accumulation was significantly higher under three than two irrigations. Fertilizer levels represented significant results on total dry matter accumulation. Maximum TDM 1539.87 g m^{-2} was observed from F_4 (144 Kg ha^{-1}) using highest fertilizer dose at final harvest 110 DAS. Minimum TDM 1006.92 g m^{-2} observed was found from F_1 (control) at final harvest. Overall mean total dry matter accumulation 1290.86g m^{-1} was found at final harvest (Fig 1b). All the treatments showed an increasing trend of total dry matter accumulation throughout the season (Fig. 1a, b).

Result indicated the maximum TDM accumulation in these treatments was probably due to more interception of the available radiation in these treatments and thus increasing mean Crop Growth Rate (CGR) during the season. Higher CGR is usually dependent upon rapid expansion of LAI to intercept available radiation, especially early in the season. The results of Chaudhary and Mehmood (1998), Gwal *et al.* (1999), Halepyati (2001) and Sabir *et al.* (2002) collaborates with the results obtained. Interaction between irrigation and fertilizer levels on biological yield was non-significant.

Leaf area duration: Irrigation levels showed non-significant results of leaf area duration (LAD). However, maximum LAD 216.50 days was observed from irrigation

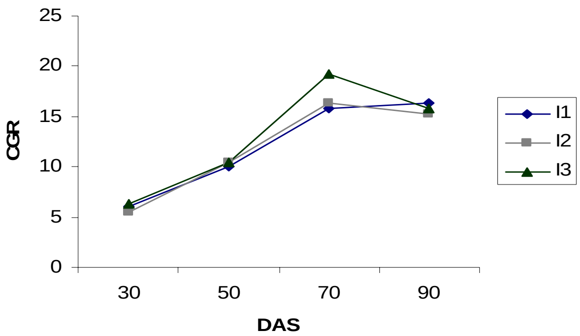

Figure 3: Effect of different irrigation levels on CGR with DAS

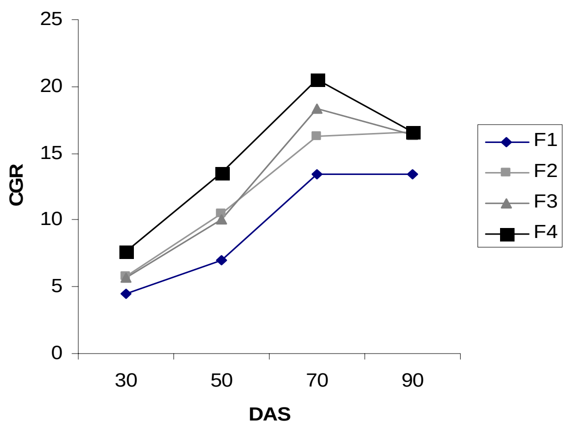

Figure 3 b: Effect of different fertilizer levels on CGR with DAS

followed by 199.93 days observed from F_2 using fertilizer rate 84 kg ha^{-1}. Minimum LAD 53.79 days was noted from control (Fig. 2b). Naeem (2001) also found that LAD increased with increasing fertilizer levels. In generally, all the treatments showed an increasing trend during the season (Fig. 2a, b).

***Crop growth rate*:** Irrigation levels used as treatment showed non-significant results; however, maximum (19.17 g m^{-2} d^{-1}) Crop Growth Rate (CGR) was observed from irrigation applied at jointing + booting and grain filling closely followed by 16.36 g m^{-2} d^{-1} observed from irrigation applied at crown root + booting and grain filling (Fig. 3a). Sharif (1999) also recorded the maximum CGR when crop was irrigated at jointing + booting and grain filling. As far as the fertilizer levels are concerned maximum crop growth rate 20.55 g m^{-2} d^{-1} was observed from F_4 (144kg ha^{-1}) closely followed by 18.31 g m^{-2} d^{-1} from F_3 using fertilizer rate at 114 kg ha^{-1} (70 DAS). The minimum values of CGR were recorded in case of control (Fig. 3b). Ali *et al.* (1998), Sabir *et al.* (1999), Naeem *et al.* (2001), warraich *et al.* (2002), also found that CGR increased with increasing fertilizer levels. In generally all the treatments i.e. irrigation as well as fertilizer levels showed an increasing trend of CGR through-out the season and became constant near harvesting (Fig. 3a, b).

Leaf area index: Leaf area index (LAI) is the main physiological determinant of crop yield. Fig. 4a and Fig. 4b represents the effect of treatments on LAI development during the season. The LAI development remained small (<1.0) up to 50 DAS there after it increased and it reached its maximum value by 70 DAS, there after LAI decreased sharply in all the treatments. Maximum LAI 5.45 was measured in the treatment using F_4 (144kg ha^{-1}) fertilizer level at 70 DAS closely followed by 4.34 using treatment F_3 (114kg ha^{-1}). In generally, all treatments showed increasing trend of LAI from 50 DAS to 80 DAS and then declined until final harvest at 125 DAS. Sharif (1999) also reported the increased LAI over control with increasing irrigation. The growth curves of LAI of wheat provide a visual integration of changes in climatic conditions. In beginning of the season, during the winter months (Dec. Jan.), LAI development rates were slow, however from Feb. onwards rapid rates of LAI development occurred as temperature increased. The sharp decline of LAI after mid Mar. was probably associated with senescence of leaves (Fig. 4a, 4b). The temperature is known to be the major determinant of LAI development in field grown cereal crops. These findings are in conformity with those of Neilson and Halvarson (1991), Fredrericck and Camberato (1995), Ali *et al.* (1998), Serrano *et al.* (2000), Naeem (2001) and Waraich et *al.* (2002).

Net assimilation rate (NAR): Data showed non-significant differences in the average Net Assimilation Rate (NAR) among different irrigation levels, and it ranged from 6.18 g m^{-2} d^{-1} to 6.31 g m^{-2} d^{-1} (Table 2). As far as fertilizer levels are concerned, maximum NAR was recorded as 6.68g m^{-2} d^{-1} in F_3. Overall mean NAR was 6.40 g m^{-2} d^{-1} during the season. The lowest value of NAR was recorded at treatment F_1 (Table 2). Naeem (2001) and Warraich *et al.* (2002) also found that NAR increased with increasing fertilizer levels.

Radiation use efficiency

Total dry matter (TDM): Maximum radiation use efficiency of 4.57 g MJ^{-1} was shown by the treatment using Irrigation level I_3. On the other hand, Maximum radiation use efficiency 5.84 g MJ^{-1} was shown by the treatment using fertilizer level F_4. Lowest RUE 2.93 g MJ^{-1} was observed in the treatment F_1. Overall mean radiation use efficiency was 4.27 g MJ^{-1} during the season (Table 2).

Grain yield: Radiation use efficiency differed significantly among different treatments. In irrigation levels maximum radiation use efficiency 814.82 g MJ^{-1} was achieved by I_3 which was statistically at PAR with 0.66 g MJ^{-1} in I_1. In addition, Maximum radiation use efficiency 856.92 g MJ^{-1} was achieved by fertilizer level F_4. Lowest radiation use efficiency 562.24 g MJ^{-1} was found in F_1. Overall mean radiation use efficiency for grain yield was 703.37 g MJ^{-1} during the season (Table 2).

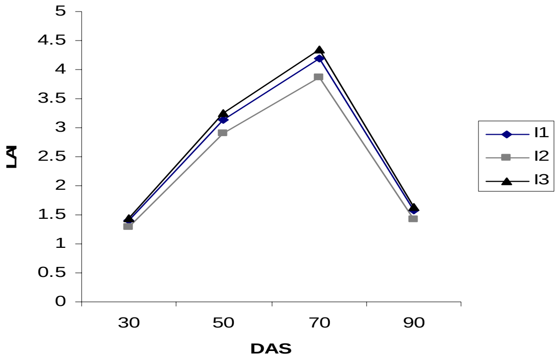

Figure 4 a. Effect of different irrigation levels on LAI with DAS

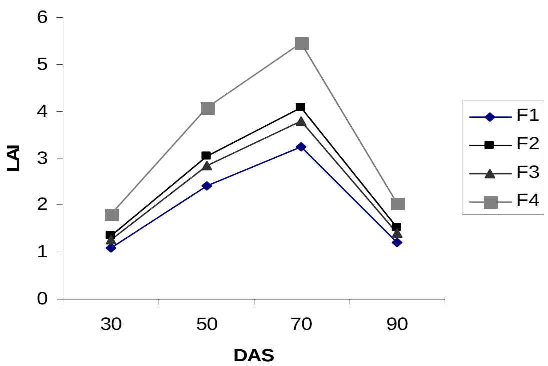

Figure 4 b. Effect of different fertilizer levels on LAI with DAS

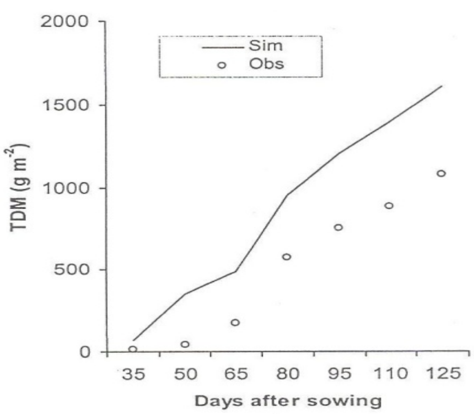

Figure 5. Changes in simulated vs observed TDM

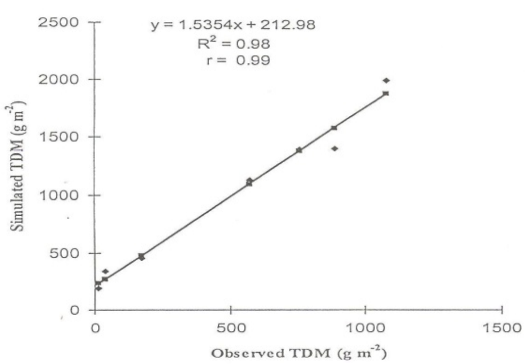

Figure 6. Relationship between observed and simulated TDM

Modeling: An on line version for simulation of crops growth and yield of Decision Support System for Agro-applied at jointing + booting and grain filling followed by 204.15 days from irrigation applied at crown root + jointing and milking (Fig. 2a). Similar findings have also been reported by Sharif (1999). Whereas, fertilizer levels showed a significant effect on LAD of wheat crop. Maximum LAD 248.77 days was recorded from F_4 (144 Kg ha^{-1}) using highest fertilizer dose closely technology Transfer (DSSAT) was employed which incorporates many models related to different field crops including CERES- WHEAT (Hoogenboom *et al.*, 1994).

Total dry matter accumulation: Fig. 5 showed that observed values for total dry matter accumulation were under estimated while simulated values were higher than the observed values in all harvests during the season and it varied from simulated values by 32.69 to 79.57%. The relationship between observed and simulated values at different harvests during the season was linear and positive. The percentage variance accounted for was 98%. The relationship between observed and simulated values of different treatments at final harvest was linear and positive. The percentage variance accounted for was 35% (Fig. 5). A regression drawn between the simulated and observed values of TDM showed a positive and linear relationship between simulated and observed values and the regression accounted for 59% variability (Fig 6) indicating satisfactory predictability by the model for yields at harvest.

CONCLUSION

In conclusion, three irrigations at jointing + booting and grain filling stage, and fertilizer level as 144 kg ha^{-1} is the best combination for having maximum output in terms of growth, yield and radiation use efficiency of the cultivar Bakhar-2000.

REFERENCES

Abderrazak, S., K.M. Ezzarouk and M.A. Muslim. 1995. Effects of water stress and nitrogen fertilizer rate on nitrogen uptake, water use and wheat yield. Al-Awamia. 89: 49 75.

Abd-Gaward, A.A., N.A. Noureldin, M.A. Ashoub and M.A. Kashabah. 1993. Studies on consumptive use and irrigation scheduling in relation to nitrogen fertilization on wheat. II response of wheat yield and its attributes. Ann. Agric. Sci. 38: 173-181.

Ali, A., M.A. Choudhry, M.A. Malik, R. Ahmad and Saifullah. 2000. Effects of various doses of nitrogen on the growth and yield of two wheat cultivars. Pak. J. Biol. Sci. 3: 1004-1005.

Ali, M.A., W. Akhtar, M. Sarwar and N. Saleem. 1998. Irrigation effect on growth and yield of wheat (*Triticum aestivum* L.). Pak. J. Agric. Res. 36: 327-332.

Chandra, B. and A. Kumar. 1999. Dry matter production and yield of wheat genotypes as influenced by irrigation frequency. Ann. Biol. 15: 209-211.

Chaudhary, A.U. and R. Mehmood. 1998. Determination of optimum level of fertilizer nitrogen for two varieties of wheat. Pak. J. Biol. Sci. 1: 351-353.

Clobanu, G.C. Hera, F. Zapata and H. Axman. 1995. Possibilities of increasing N use efficiency in winter and spring wheat. Anslele institution de cercetari Pentru mklcereale si plante technice fundulae. 62: 121-137. Field Crop absts. 48: 5277; 1995.

Frederick, J.R. and J.J. Camberato. 1995. Water and nitrogen effects on winter wheat in the south eastern coastal plain: I. Physiological responses. Agron. J. 87: 527- 533.

Garabet, S., M. Wood and J. Royan. 1998. Nitrogen and water effects on wheat yield in Mediterranean type climate-I. Growth, water use and nitrogen accumulation. Field Crop Res. 57: 309-318.

Ghazal, H.M. Wassouf, M.M. Nachit and A.A. Jaradat. 1998. Yield and yield components of durum wheat as influenced by irrigation and nitrogen fertilization. Proc. 3rd Int. Triticeae symp. Aleppo, Syria, 4-8 May: 445-449 (CAB. Absts. 1998).

Gwal, H.B., R.J. Tiwari, R.C. Jain and F.S. Prajapati. 1999. Effects of different levels of fertilizer on growth, yield and quality of late sown wheat. RACHIS newsletter. 18: 42- 44.

Halepyati, A.S. 2001. Influence of irrigation and nitrogen levels on growth and yield of wheat. Karnataka. J. Agric. Sci. 14: 449-450.

Hameed, E.A. Shah, A.A. Shad, J. Bakht and T. Muhammad. 2003. Effect of different planting dates, seed rate and nitrogen levels on wheat. Asian. J. Pl. Sci. 2: 467-474.

Hoogenboom, G., W. J. Jones, P.W. Wilkens, W.D. Batchelor, W.T. Boown, L.A. Hunt, N.B. Pickering, U. Singh, D.C. Goodwin, B. Baer, K.J. boote, J.T. Ritchie and J.W. White. 1994. Crop models p. 95- 244. In G.Y. Tsuji, G. Uehara and S. Balas (ed.) DSSAT ver. 3. vol. 2 Univ. Hawaii. Honolulu.

Hunt, R. 1978. Plant Growth Analysis. Edward Arnold (Pub.) Ltd. 96:8-38.

Jan, M.T., M. Shah and S. Khan. 2002. Type of N- fertilizer rate and timing effect on wheat production. Sarhad j. Agri. 18: 405-410.

Jana, P.K., A.K. Mitra, N.C. Mandal, M.K. Dasgupta, D.C. Ghosh, S.K. Mukhopadhgay, D.D. Gupta and D.K. Majumadar. 1995. Effect of irrigation growth, yield and consumptive use efficiency of wheat in teroi soils of North Bengal. Proc. of National Sympo. Held at Visva Bharti, Sriniketa, West Bengal, on 18-21 Feb: 180-184.

Kao, W.Y. and I.N. Forseth. 1992. Responses of gas exchange and phototropic leaf orientation in soybean to soil water availability, leaf water potential, air temperature and photosynthetic photon flux. Environ. Exp. Bot. 32:153-161.

Karim, A.J.M.S., K. Egashira and M.J. Abedin. 1997. Interaction effects of irrigation and nitrogen fertilization on yield and water use of wheat, grown in a clay terrace soil in Bangladesh. Bull. Inst. Tropical Agri., Kyushu Univ., 20: 17-26 (CAB. Absts, 1997).

Khaliq, A., M. Iqbal and S.M.A. Basra. 1999. Optimization of seeding density and nitrogen application in wheat cv. Inqlab-91 under Faisalabad conditions. Int. J. Agri. Biol. 1: 241-243.

Khan, S., N.D. Shah and M.T. Sheikh. 2000. Effect and economic of different levels of nitrogen fertilizer on the yield of zargoon wheat variety under irrigated conditions of Baluchistan. Sarhad J. Agri. 16: 581-585.

Lathwal, O.P. and T. Singh. 1992. Effect of irrigation and nitrogen levels on yield attributes and yield of wheat. Haryana J. Agron. 8: 69-70.

Makowski, D., D. Wallach and J.M. Meynard. 1999. Model of yield, grain protein and residual mineral nitrogen response to applied nitrogen for winter wheat, Agron. J. 91: 337-385.

Maqsood, M., A. Ali, Z. Aslam, M. Saeed and S. Ahmad. 2002. Effect of irrigation and nitrogen levels on grain yield and quality of wheat. Int. J. Agri. Biol. 4: 164-165.

Matsunaka, T., H. Takeuchi and T. Miyawaki. 1992. Optimum irrigation period for grain production in spring wheat. Soil Sci. Op. and Pl. Nutr. 38: 269-279.

Monteith, J.L. and J.F. Elston. 1983. Performance and productivity of foliage in the field. In the growth and function of leaves. (Eds. J.E. Dale and Milthorpe) Camb Univ. Press, Butterworths, London, p 499-518.

Naeem. 2001. Growth, radiation use efficiency and yield of new cultivars of wheat under variable nitrogen rates. M. Sc. Agri. Thesis, Univ. Agric., Faisalabad.

Nazir, M.S., A. Jabbar, Z. Waheed, A. Ghaffar and M. Aslam. 2000. Response of late sown wheat to seeding density and nitrogen management. Pak. J. Biol. Sci. 3: 998-1001.

Neilsen, D.C. and A.D. Halvorson. 1991. Nitrogen fertility influence on water stress and yield of winter wheat. Agron. J. 83:1065-1070.

Osborne, S.L., J.S. Schepers, D.D. Francis and M.R. Schlemmer. 2002. Use of spectral radianceto estimate in-season biomass and grain yield in nitrogen and water stressed corn. Crop Sci. 42:165-171.

Oweise, T., M. Pala and J. Ryan. 1999. Management alternatives for improved durum wheat production under supplemental irrigation in Syria. European J. Agron. 11:255-266.

Rajender, K., S. Kumar and S. Singh. 1998. Ameliorative measures for moisture stress at crown root initiation stage for sustainable wheat. Agric. Sci. digest (Karnal), 18: 39-42.

Rajput, M.K.K., A.H. Ansari, S.A. Rao, K.A. Mahar and Z.M. Shaikh. 1994. Influence of irrigation frequencies on the growth and grain yield of bread wheat varieties. Pak. J. Agri., Agric. Engg. Vet. Sci. 10: 64-69.

Sabir, S., J. Bakht, M. Shafi and W.A. Shah. 2002. Effect of foliar vs. broadcast application of different doses of nitrogen on wheat. Asian. J. Plant Sci. 1: 300-303.

Sabry, S.R.S., E.M. Taha, and A.A. Khattab. 1999. Response of long spike wheat (*Triticum aestivum* L.) genotypes to nitrogen fertilizer levels in soils of Middle Egypt. Bull. Fac. Agri. Univ. Cairo. 50: 169-188.

Serrano, L., I. Fillella and J. Penuelas. 2000. Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. Crop. Sci. 40: 723-731.

Sharif, M. 1999. Effect of irrigation at different growth stages on growth and yield performance of wheat cultivars. M.Sc. Agri. Thesis, Uni. Agric., Faisalabad.

Steel, R.G.D. and J.H. Torrie. 1997. Principles and Procedures of Statistics 2nd Ed. McGraw Hill Book Co. Inc. Singapore: 172-177.

Warraich, E.A., N. Ahmad, S.M.A. Basra and I. Afzal. 2002. Effect of nitrogen on source- sink relationship in wheat. Int. J. Agri. Biol. 4: 300-302.

Zbiec, I.I., Z. Koszanski and C. Podsiadio. 1998. Reakcja trzech odmian Pszenicy Jarej na deszezowanie I nawozenie mineralne na glebie lekkiej. 438: 345-350 (Field Crop Absts., 51: 1437; 1998).